AD/A-001 697

TUNNEL HULL CAVITATION AND PROPELLER INDUCED PRESSURE INVESTIGATION

James G. Peck

Naval Ship Research and Development Center

Prepared for:

Naval Ship Engineering Center

November 1974

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Naval Ship Research and Development Center
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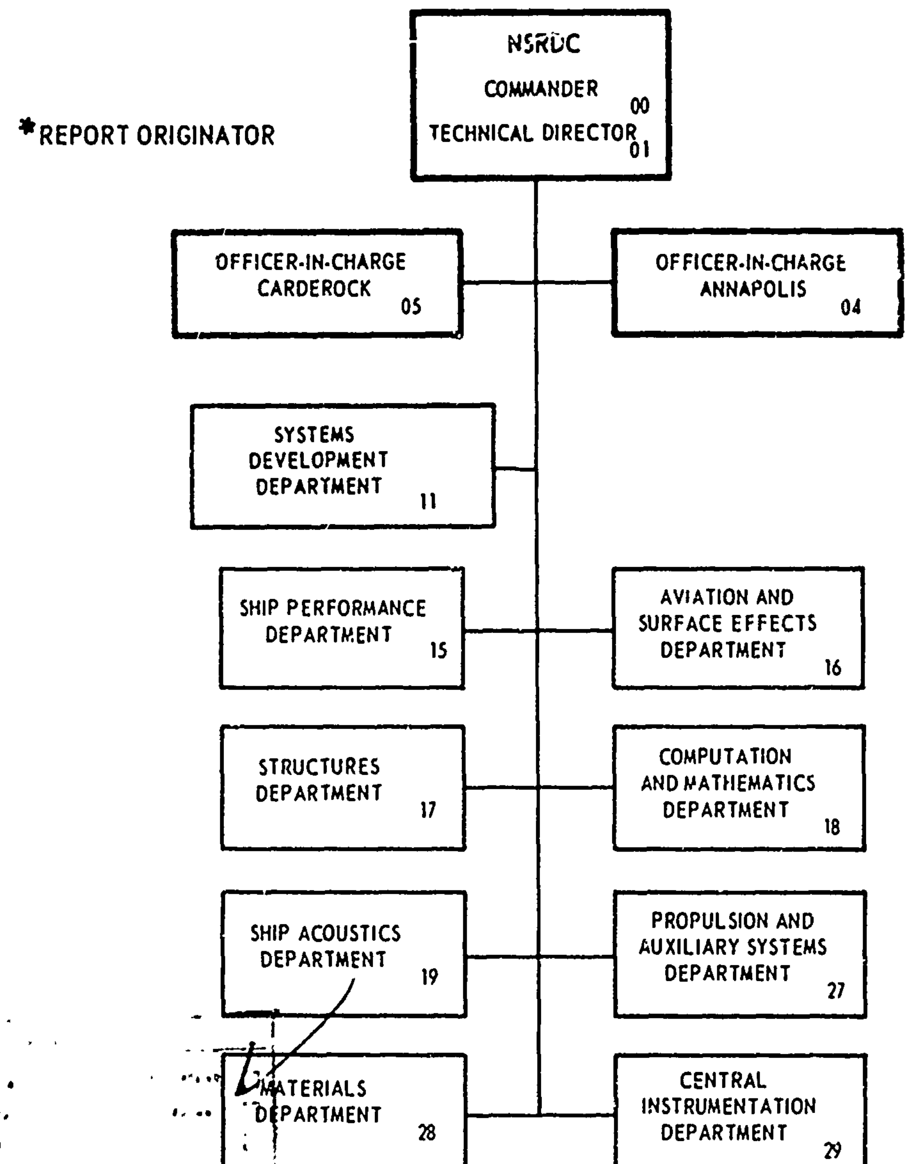

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER SPD-597-01	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER AD/A-001697
4. TITLE (and Subtitle) TUNNEL HULL CAVITATION AND PROPELLER INDUCED PRESSURE INVESTIGATION		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) James G. Peck		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Ship Research & Development Center Bethesda, Maryland 20084		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NAVSECNORDIV Funding, Project Order #4-0056, W.U. 1532-340
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Sh gineering Center Norfolk Division Norfolk, inia		12. REPORT DATE November 1974
		13. NUMBER OF PAGES 38
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIEED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Tunnel hull
Blade-frequency harmonics

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Cavitation performance of two propellers at different hull clearance-to-diameter ratios in a tunnel hull model are presented, as well as the propeller-induced pressures measured in the tunnel wall. Cavitation performance of the two propellers in uniform flow is also included. The propellers operating in the tunnel hull were found to be more efficient than in uniform flow. Predominate features of the induced pressure measurements were the blade-frequency harmonics. There was no evidence of flow separation on the

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

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tunnel hull model at simulated ship speeds of 45 knots.

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NOTATION

$c_{0.7}$	Blade-section length at 0.7 radius [ft]
D	Propeller diameter [ft]
J	Advance coefficient, $J = V_A/ND$
K_p	Nondimensional pressure coefficient, $K_p = p/\rho N^2 D^2$
K_{p_Z}	Nondimensional blade-frequency pressure coefficient, $K_{p_Z} = p_Z/\rho N^2 D^2$
K_Q	Torque coefficient, $K_Q = Q/\rho N^2 D^5$
K_T	Thrust coefficient, $K_T = T/\rho N^2 D^4$
N	Propeller revolutions per unit time
p	Pressure [lb/ft^2]
p_∞	Ambient static pressure [lb/ft^2]
p_v	Ambient vapor pressure [lb/ft^2]
Q	Torque [ft-lb]
R_n	Reynolds number at 0.7R, $R_N = c_{0.7} \dfrac{V_A^2 + (0.7\pi ND)^2}{\nu}$
T	Propeller thrust [lb]
V	Ship speed [knots]
V_A	Speed of advance of propeller, positive forward, $V_A = (1 - w)V$ [ft/sec]
w	Taylor wake fraction, based on thrust identity, $w = (V - V_A)/V$
η	Efficiency $\eta = TV/2\pi Qn$
ρ	Mass density of water [lb - sec^2/ft^4]

σ Cavitation number $\sigma = \dfrac{p_\infty - p_v}{1/2 \rho V^2}$

ν Kinematic viscosity of water [ft^2/sec]

ABSTRACT

Cavitation performance of two propellers at different hull clearance-to-diameter ratios in a tunnel hull model are presented, as well as the propeller-induced pressures measured in the tunnel wall. Cavitation performance of the two propellers in uniform flow is also included. The propellers operating in the tunnel hull were found to be more efficient than in uniform flow. Predominate features of the induced pressure measurements were the blade-frequency harmonics. There was no evidence of flow separation on the tunnel hull model at simulated ship speeds of 45 knots.

INTRODUCTION

Hull tunnels have been proposed as a means of decreasing the navigational depth of small high-performance craft. Model experiments[1] have shown that a decrease in navigational depth requirements can be accomplished without loss of speed-power performance of the craft.

The high propeller shaft angles required on many small high-performance craft (12 degrees or more) have been found to be a major cause of propeller root erosion.[2] The use of tunnel hull construction permits a reduction in the propeller shaft angle (5 degrees in Reference 1).

The Naval Ship Research and Development Center (NSRDC) was requested by the Naval Ship Engineering Center, Norfolk Division to determine the cavitation performance of a propeller operating in a deep tunnel hull.

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[1] Harbaugh, K. H. and D. L. Blount, "An Experimental Study of a High Performance Tunnel Hull Craft," presented before the Society of Naval Architects and Marine Engineers, Lake Buena Vista, Florida (Apr 1973)

[2] Peck, J. G. and D. H. Moore, "Inclined-Shaft Propeller Performance Characteristics," NSRDC Report 4127 (Apr 1974)

It was anticipated that a cavitating propeller in the close vicinity of the tunnel walls might induce relatively large pressure-fluctuations on the wall. In order to provide design information on the required plate-thickness in the vicinity of tunnel-hull propellers, pressures in the wall of the tunnel hull were also measured. The cavitation performance of the tunnel was determined through visual observation and photography.

A drawing of the tunnel hull and photographs of the propellers used in these experiments are shown in Figure 1. Geometry of the propellers and the scope of the experimental program are given in Tables 1 and 2, respectively.

DESCRIPTION OF FACILITIES AND EXPERIMENTAL PROCEDURE

Propeller open-water characteristics were obtained in the Center's deep water towing basin. Cavitation characteristics of the propellers were obtained in the 24-inch variable-pressure water tunnel. Tunnel water velocities for each propeller, in uniform flow and in the model tunnel hull, were established by setting the thrust values in the water tunnel equal to the thrust values obtained from the open water characteristics tests at the same advance coefficient. The water velocity at the propeller was 20 fps and tunnel pressures were used to cover a range of cavitation numbers at the proceller of 0.5 to 7.5.

The model hull tunnel was mounted in a flat plate attached to the floor of the water tunnel. Three pressure transducers were mounted in the wall of the hull tunnel as shown in Figure 1. The center pressure transducer was mounted in the plane of the propeller disk. The forward transducer was 1.25 inches from the propeller plane and the after transducer was 1.50 inches from the propeller plane. The pressure at each transducer was recorded on magnetic tape and digitized and analyzed by an Analog-Digital Converter and an Interdata Corporation Model 4 Minicomputer.

REDUCTION AND ANALYSIS OF THE EXPERIMENTAL RESULTS

PROPELLER CHARACTERISTICS DATA

The open-water characteristics of the propellers were reduced to the usual nondimensional coefficients of thrust and torque. Characteristics curves of these propellers are presented in Figures 2 and 3. (Reynolds number for the open water characterizations ranged from 2.3×10^5 to 5.6×10^5.)

The thrust and torque data from the cavitation experiments were reduced to nondimensional coefficients K_T and K_Q. Efficiencies, K_T/J^2, and K_Q/J^3 were calculated from faired values of K_T and K_Q. All force coefficients are given in Tables 3 through 6. The speed coefficients and cavitation numbers are always measured at the propeller in order to facilitate comparison of in-hull and uniform flow propeller performance. The cavitation numbers cover a range of ship speeds from 11.8 to 40.3 knots.

The cavitation performance of the two propellers is presented in Figures 4 through 7. These curves represent the faired data contained in Tables 3 through 6. The results presented seem compatible, except for one set of data for Propeller 4175. Operating in the tunnel hull (Figure 5) at a cavitation number of 1.937, the torque of Propeller 4175 was higher than expected, resulting in an efficiency lower than would seem reasonable. The reduced data are also shown in Figures 8 through 11 as propeller efficiency versus K_T/J^2 for each propeller. These curves will enable the user to estimate propeller performance for varying conditions of thrust and cavitation index.

HULL-PRESSURE DATA

The pressure measured at each transducer was recorded for at least 200 propeller revolutions, digitized, and averaged. The average wave form data representing the hull-pressure variation over a propeller revolution was then entered into a Fourier analysis program. Typical rotational variation of pressure amplitudes for each propeller at $K_T/J^2 = 0.2$ and cavitation number of 3.4 are shown in Figures 12 and 13. The zero degree reference for propeller rotation was with the blade centerline 90 degrees past the pressure transducers in the direction of rotation. Both figures show the predominance of the blade frequency harmonic. It appears from the data that the minimum pressure occurs at the transducers just as the trailing edge of a propeller blade passes the transducers.

The measured blade-frequency pressure amplitudes for each propeller are presented in Figures 14 and 15. Both figures show the effect of cavitation number on measured pressure in the plane of the propeller. Pressures measured forward and aft of the propeller did not show any trends attributable to cavitation number. As can be seen, the blade frequency pressure amplitude in the plane of the propeller can be quite large.

Figure 16 shows the effect of hull clearance on the measured blade-frequency pressure amplitude for the two hull clearances used in these experiments, at various propeller loadings. The slopes of the curves indicate that there may be some common minimum pressure amplitude independent of loading (K_T/J^2), at a hull clearance to diameter ratio beyond the range of the experiments (about hull clearance/diameter ratio of 0.2). This possibility may be worth further exploration.

Sketches of cavitation present on the propellers are presented in Figure 17. These sketches illustrate the changes in cavitation present on the propeller as it rotates through the variable flow field. The area of cavitation on the propeller, operating in uniform flow, is between the extremes of cavitation present when the propeller is operating on the model, although tending to be more like the heaviest cavitation condition.

Not shown in the sketches but observed during these experiments was cavitation which occurred between the tunnel wall and the tips of the propeller operating with the minimum hull clearance. The cavitation was present at the lightest propeller loading and disappeared as propeller loading was increased. This cavitation was not present between the tunnel wall and the tips of the propeller at the larger hull clearance.

The RPM limit of the dynamometer driving the propellers limited the simulated ship speed for which a range of advance coefficients could be achieved to 40.3 knots. However, the water speed in the water tunnel was raised to simulated ship speed of 45 knots for one lightly loaded propeller condition and observations of the model tunnel hull made. There was no evidence of flow seperation on any part of the model tunnel.

Photographs of the two propellers, in the tunnel hull and in uniform flow, are presented in Figures 18 and 19.

CONCLUSIONS AND RECOMMENDATIONS

These experiments show that for the same propeller loading propeller efficiency was higher operating in the tunnel hull than operating in uniform flow. This verifies the point made in Reference 1 that a

tunnel hull propulsion arrangement is comparable to the conventional shafting arrangement in terms of propulsive efficiency.

There was no flow seperation on the model tunnel hull through simulated ship speeds of 45 knots. The extent of cavitation present on the propellers in uniform flow is between the extremes of cavitation present during one revolution of the propeller in the tunnel hull. The cavitation in uniform flow fairly well represents the cavitation present on the propeller in the tunnel hull in the lower water velocity portion of one revolution.

Induced pressures measured in the tunnel wall showed that there were no harmonics in the pressure signal of comparable magnitude to the blade-frequency harmonic. Blade-frequency pressure amplitudes increase as propeller loading increases. Blade-frequency induced pressure decreased with increasing hull clearance to diameter ratio. Induced pressures were greater in the plane of the propellers than either forward or aft. Induced pressures were larger forward of the propeller than aft. Values of blade-frequency pressure amplitudes determined in the experiments indicated quite large full-scale forces.

Results of the experiments indicate that the desirability of further experiments with hull clearance a parameter. These experiments should be conducted measuring pressures on a flat plate which would provide data of a more generally applicable nature than a tunnel hull model. In addition, a series of experiments should be conducted with propeller diameter as the parameter to verify that blade-frequency pressure amplitude coefficients can be scaled.

REFERENCES

1. Harbaugh, K. H. and D. L. Blount, "An Experimental Study of a High Performance Tunnel Hull Craft," presented before the Society of Naval Architects and Marine Engineers, Lake Buena Vista, Fla. (Apr 1973)

2. Peck, J. G. and D. H. Moore, "Inclined-Shaft Propeller Performance Characteristics," NSRDC Report 4127 (Apr 1974)

TABLE 1

Geometry of Model Propellers

NSRDC Propeller Number	Nominal Pitch-Diameter Ratio	Model Propeller Diameter inches	Number of Blades	Hull Clearance to Diameter Ratio
4175	1.27	6.00	3	0.021
4214	1.43	5.25	3	0.095

TABLE 2

Experimental Program

In Uniform Flow

NSRDC Propeller Number	Wake Fraction	Propeller Advance Coefficient	Propeller Cavitation Number	Ship Cavitation Number
4175	1.0	0.8-1.30	0.5-7.5	0.388-5.81
4214	1.0	0.9-1.55	0.5-7.5	0.442-6.63
In Tunnel Hull				
4175	0.88	0.8-1.29	0.565-7.5	0.5-5.81
4214	0.94	0.9-1.55	0.565-6.58	0.5-5.81

PROPELLER NUMBER =4175 PITCH RATIO = 1.27 SIGMA = 7.500

J	KTOUT	10KQOUT	EFFIC	KT/J2	KQ/J3
.8000	.2409	.4853	.6323	.3764	.0947
.8500	.2166	.4541	.6453	.2998	.0739
.9000	.1935	.4185	.6623	.2389	.0574
.9500	.1706	.3804	.6782	.1891	.0444
1.0000	.1475	.3413	.6876	.1475	.0341
1.0500	.1237	.3020	.6846	.1122	.0261
1.1000	.0994	.2624	.6634	.0822	.0197
1.1500	.0750	.2218	.6185	.0567	.0146
1.2000	.0510	.1788	.5444	.0354	.0103
1.2500	.0283	.1309	.4307	.0181	.0067
1.3000	.0084	.0754	.2311	.0050	.0034

PROPELLER NUMBER =4175 PITCH RATIO = 1.27 SIGMA = 3.874

J	KTOUT	10KQOUT	EFFIC	KT/J2	KQ/J3
.8000	.2527	.4795	.6709	.3948	.0937
.8500	.2244	.4521	.6713	.3105	.0736
.9000	.1985	.4185	.6793	.2450	.0574
.9500	.1742	.3809	.6913	.1930	.0444
1.0000	.1507	.3412	.7031	.1507	.0341
1.0500	.1276	.3005	.7098	.1158	.0260
1.1000	.1046	.2598	.7046	.0864	.0195
1.1500	.0813	.2194	.6785	.0615	.0144
1.2000	.0579	.1791	.6175	.0402	.0104
1.2500	.0345	.1384	.4961	.0221	.0071
1.3000	.0115	.0961	.2467	.0068	.0044

PROPELLER NUMBER =4175 PITCH RATIO = 1.27 SIGMA = 1.937

J	KTOUT	10KQOUT	EFFIC	KT/J2	KQ/J3
.8000	.2505	.4995	.6384	.3913	.0976
.8500	.2315	.4707	.6653	.3204	.0766
.9000	.2078	.4348	.6846	.2566	.0596
.9500	.1819	.3948	.6967	.2016	.0460
1.0000	.1556	.3528	.7018	.1556	.0353
1.0500	.1299	.3102	.7000	.1179	.0268
1.1000	.1057	.2679	.6909	.0874	.0201
1.1500	.0830	.2261	.6721	.0628	.0149
1.2000	.0613	.1842	.6354	.0426	.0107
1.2500	.0395	.1412	.5567	.0253	.0072
1.3000	.0160	.0951	.3482	.0095	.0043

PROPELLER NUMBER =4175 PITCH RATIO = 1.27 SIGMA = 1.291

J	KTOUT	10KQOUT	EFFIC	KT/J2	KQ/J3
.8000	.1767	.3874	.5807	.2761	.0757
.8500	.2028	.4276	.6414	.2806	.0696
.9000	.2021	.4243	.6822	.2495	.0582
.9500	.1851	.3946	.7088	.2051	.0461
1.0000	.1599	.3524	.7223	.1599	.0352
1.0500	.1325	.3062	.7231	.1202	.0264
1.1000	.1066	.2616	.7134	.0881	.0197
1.1500	.0837	.2147	.6970	.0633	.0144
1.2000	.0630	.1779	.6769	.0438	.0103
1.2500	.0418	.1293	.6428	.0267	.0066
1.3000	.0147	.0636	.4815	.0087	.0029

PROPELLER NUMBER =4175 PITCH RATIO = 1.27 SIGMA = .645

J	KTOUT	10KQOUT	EFFIC	KT/J2	KQ/J3
.8000	.0923	.2287	.5139	.1442	.0447
.8500	.0960	.2344	.5539	.1328	.0382
.9000	.1059	.2570	.5900	.1307	.0353
.9500	.1157	.2808	.6230	.1282	.0328
1.0000	.1210	.2947	.6535	.1210	.0295
1.0500	.1188	.2918	.6806	.1078	.0252
1.1000	.1081	.2698	.7014	.0893	.0203
1.1500	.0893	.2308	.7084	.0676	.0152
1.2000	.0649	.1814	.6826	.0450	.0105
1.2500	.0386	.1326	.5791	.0247	.0068
1.3000	.0163	.0998	.3374	.0096	.0045

PROPELLER NUMBER =4175 PITCH RATIO = 1.27 SIGMA = .500

J	KTOUT	10KQOUT	EFFIC	KT/J2	KQ/J3
.9000	.0808	.1979	.5846	.0997	.0271
.9500	.0808	.1944	.6285	.0895	.0227
1.0000	.0918	.2199	.6648	.0918	.0220
1.0500	.1000	.2415	.6919	.0907	.0209
1.1000	.0969	.2395	.7084	.0801	.0180
1.1500	.0799	.2074	.7052	.0604	.0136
1.2000	.0519	.1521	.652[illegible]	.0361	.0088
1.2500	.0215	.0935	.4578	.0138	.0048
1.3000	.0028	.0651	.0903	.0017	.0030

TABLE 3 - Cavitation Performance Characteristics of Propeller 4175 in Uniform Flow

PROPELLER NUMBER =4175 PITCH RATIO = 1.27 SIGMA = 7.500

J	KTOUT	10KQOUT	EFFIC	KT/J2	KQ/J3
.8000	.2408	.4528	.6770	.3762	.0884
.8500	.2166	.4159	.7046	.2998	.0677
.9000	.1935	.3820	.7254	.2389	.0524
.9500	.1706	.3484	.7403	.1890	.0406
1.0000	.1474	.3129	.7494	.1474	.0313
1.0500	.1236	.2747	.7518	.1121	.0237
1.1000	.0993	.2337	.7441	.0821	.0176
1.1500	.0749	.1907	.7189	.0566	.0125
1.2000	.0510	.1476	.6594	.0354	.0085
1.2500	.0284	.1070	.5276	.0182	.0055
1.3000	.0084	.0727	.2389	.0050	.0033

PROPELLER NUMBER =4175 PITCH RATIO = 1.27 SIGMA = 3.874

J	KTOUT	10KQOUT	EFFIC	KT/J2	KQ/J3
.8000	.2389	.4931	.6168	.3732	.0963
.8500	.2134	.4545	.6353	.2954	.0740
.9000	.1891	.4102	.6604	.2335	.0563
.9500	.1657	.3647	.6868	.1836	.0425
1.0000	.1427	.3210	.7076	.1427	.0321
1.0500	.1199	.2806	.7143	.1088	.0242
1.1000	.0969	.2435	.6966	.0801	.0183
1.1500	.0731	.2081	.6430	.0553	.0137
1.2000	.0481	.1716	.5359	.0334	.0099
1.2500	.0214	.1293	.3294	.0137	.0066
1.3000	-.0077	.0752	-.2111	-.0045	.0034

PROPELLER NUMBER =4175 PITCH RATIO = 1.27 SIGMA = 1.937

J	KTOUT	10KQOUT	EFFIC	KT/J2	KQ/J3
.8000	.2196	.4664	.5996	.3432	.0911
.8500	.2112	.4498	.6350	.2923	.0732
.9000	.1937	.4275	.6489	.2391	.0586
.9500	.1707	.3981	.6485	.1892	.0464
1.0000	.1452	.3613	.6395	.1452	.0361
1.0500	.1189	.3179	.6253	.1079	.0275
1.1000	.0933	.2696	.6060	.0771	.0203
1.1500	.0686	.2194	.5738	.0520	.0144
1.2000	.0449	.1710	.5021	.0312	.0099
1.2500	.0208	.1293	.3195	.0133	.0066
1.3000	-.0056	.1004	-.1160	-.0033	.0046

PROPELLER NUMBER =4175 PITCH RATIO = 1.27 SIGMA = 1.291

J	KTOUT	10KQOUT	EFFIC	KT/J2	KQ/J3
.8000	.1923	.3821	.6406	.3004	.0746
.8500	.1945	.3875	.6790	.2692	.0631
.9000	.1878	.3807	.7068	.2319	.0522
.9500	.1742	.3621	.7272	.1930	.0422
1.0000	.1551	.3329	.7417	.1551	.0333
1.0500	.1324	.2951	.7500	.1201	.0255
1.1000	.1075	.2511	.7495	.0888	.0189
1.1500	.0817	.2042	.7323	.0618	.0134
1.2000	.0563	.1584	.6791	.0391	.0092
1.2500	.0325	.1183	.5464	.0208	.0061
1.3000	.0112	.0893	.2605	.0067	.0041

PROPELLER NUMBER =4175 PITCH RATIO = 1.27 SIGMA = .645

J	KTOUT	10KQOUT	EFFIC	KT/J2	KQ/J3
.8000	.1156	.2477	.5941	.1806	.0484
.8500	.1244	.2728	.6166	.1721	.0444
.9000	.1326	.2909	.6528	.1637	.0399
.9500	.1361	.2976	.6913	.1508	.034[illegible]
1.0000	.1322	.2905	.7243	.1322	.0291
1.0500	.1200	.2693	.7444	.1088	.0233
1.1000	.0954	.2355	.7419	.0825	.0177
1.1500	.0739	.1928	.7010	.0558	.0127
1.2000	.0457	.1467	.5953	.0318	.0085
1.2500	.0266	.1047	.3921	.0132	.0054
1.3000	.0054	.0765	.1455	.0032	.0035

TABLE 4 - Cavitation Performance Characteristics of Propeller 4175 in the Tunnel Hull

PROPELLER NUMBER =4214 PITCH RATIO = 1.43 SIGMA = 6.580

J	KTOUT	10KQOUT	EFFIC	KT/J2	KQ/J3
.9000	.3278	.7446	.6305	.4046	.1021
.9500	.2990	.6872	.6577	.3313	.0802
1.0000	.2729	.6364	.6825	.2729	.0636
1.0500	.2488	.5902	.7043	.2256	.0510
1.1000	.2259	.5470	.7230	.1867	.0411
1.1500	.2038	.5053	.7381	.1541	.0332
1.2000	.1819	.4638	.7491	.1263	.0268
1.2500	.1600	.4214	.7553	.1024	.0216
1.3000	.1378	.3773	.7555	.0815	.0172
1.3500	.1151	.3306	.7480	.0632	.0134
1.4000	.0920	.2809	.7295	.0469	.0102
1.4500	.0685	.2279	.6935	.0326	.0075
1.5000	.0448	.1713	.62[illegible]	.0199	.0051
1.5500	.0213	.1114	.4716	.0089	.0030

PROPELLER NUMBER =4214 PITCH RATIO = 1.43 SIGMA = 3.395

J	KTOUT	10KQOUT	EFFIC	KT/J2	KQ/J3
.9000	.3376	.7809	.6192	.4168	.1071
.9500	.3098	.7142	.6558	.3432	.0833
1.0000	.2837	.6568	.6874	.2837	.0657
1.0500	.2590	.6066	.7137	.2350	.0524
1.1000	.2356	.5614	.7349	.1947	.0422
1.1500	.2132	.5192	.7516	.1612	.0341
1.2000	.1915	.4783	.7646	.1330	.0277
1.2500	.1702	.4371	.7747	.1089	.0224
1.3000	.1490	.3940	.7827	.0882	.0179
1.3500	.1277	.3477	.7890	.0701	.0141
1.4000	.1058	.2970	.7938	.0540	.0108
1.4500	.0831	.2409	.7962	.0395	.0079
1.5000	.0592	.1785	.7920	.0263	.0053
1.5500	.0338	.1091	.7637	.0141	.0029

PROPELLER NUMBER =4214 PITCH RATIO = 1.43 SIGMA = 1.697

J	KTOUT	10KQOUT	EFFIC	KT/J2	KQ/J3
.9000	.2914	.7207	.5701	.3597	.0989
.9500	.2933	.6959	.6373	.3250	.0812
1.0000	.2834	.6642	.6791	.2834	.0664
1.0500	.2655	.6270	.7075	.2408	.0542
1.1000	.2427	.5856	.7256	.2006	.0440
1.1500	.2177	.5407	.7367	.1646	.0356
1.2000	.1923	.4933	.7443	.1335	.0286
1.2500	.1679	.4439	.7523	.1074	.0227
1.3000	.1451	.3928	.7643	.0859	.0179
1.3500	.1241	.3402	.7834	.0681	.0138
1.4000	.1041	.2861	.8112	.0531	.0104
1.4500	.0842	.2321	.8443	.0400	.0075
1.5000	.0623	.1717	.8660	.0277	.0051
1.5500	.0361	.1105	.8059	.0150	.0030

PROPELLER NUMBER =4214 PITCH RATIO = 1.43 SIGMA = 1.131

J	KTOUT	10KQOUT	EFFIC	KT/J2	KQ/J3
.9000	.2010	.5436	.5296	.2482	.0746
.9500	.2330	.5962	.5908	.2581	.0695
1.0000	.2466	.6149	.6393	.2466	.0614
1.0500	.2463	.6057	.6795	.2234	.0523
1.1000	.2357	.5786	.7131	.1948	.0435
1.1500	.2179	.5387	.7402	.1648	.0354
1.2000	.1957	.4914	.7606	.1359	.0284
1.2500	.1712	.4404	.7732	.1095	.0225
1.3000	.1459	.3886	.7769	.0863	.0177
1.3500	.1211	.3378	.7701	.0664	.0137
1.4000	.0972	.2886	.7503	.0496	.0105
1.4500	.0743	.2405	.7128	.0353	.0079
1.5000	.0519	.1918	.6455	.0230	.0057
1.5500	.0289	.1397	.5101	.0120	.0038

PROPELLER NUMBER =4214 PITCH RATIO = 1.43 SIGMA = .500

J	KTOUT	10KQOUT	EFFIC	KT/J2	KQ/J3
1.0000	.1155	.3162	.5814	.1155	.0316
1.0500	.1239	.3317	.6240	.1124	.0287
1.1000	.1348	.3578	.6597	.1114	.0269
1.1500	.1440	.3831	.6881	.1089	.0252
1.2000	.1483	.3992	.7098	.1030	.0231
1.2500	.1457	.4001	.7247	.0933	.0205
1.3000	.1354	.3828	.7320	.0801	.0174
1.3500	.1177	.3467	.7293	.0646	.0141
1.4000	.0941	.2942	.7126	.0480	.0107
1.4500	.0672	.2301	.6744	.0320	.0075
1.5000	.0410	.1622	.6040	.0182	.0048
1.5500	.0205	.1097	.5008	.0085	.0027

TABLE 5 - Cavitation Performance Characteristics of Propeller 4214 in Uniform Flow

PROPELLER NUMBER =4214 PITCH RATIO = 1.43 SIGMA = 6.580

J	KTOUT	10KQOUT	EFFIC	KT/J2	KQ/J3
1.0000	.2721	.6044	.7166	.2721	.0604
1.0500	.2473	.5520	.7406	.2243	.0477
1.1000	.2247	.5121	.7481	.1857	.0385
1.1500	.2032	.4783	.7775	.1536	.0314
1.2000	.1820	.4457	.7801	.1264	.0258
1.2500	.1606	.4104	.7784	.1028	.0210
1.3000	.1385	.3700	.7743	.0819	.0168
1.3500	.1155	.3232	.7680	.0634	.0131
1.4000	.0919	.2701	.7577	.0469	.0099
1.4500	.0680	.2126	.7380	.0323	.0070
1.5000	.0443	.1527	.6920	.0197	.0045
1.5500	.0216	.0947	.5634	.0090	.0025

PROPELLER NUMBER =4214 PITCH RATIO = 1.43 SIGMA = 3.395

J	KTOUT	10KQOUT	EFFIC	KT/J2	KQ/J3
1.0000	.2747	.6399	.6832	.2747	.0640
1.0500	.2498	.5891	.7084	.2265	.0509
1.1000	.2274	.5461	.7291	.1880	[illegible]
1.1500	.2063	.5064	.7456	.1560	[illegible]
1.2000	.1852	.4668	.7578	.1286	[illegible]
1.2500	.1634	.4251	.7647	.1046	.0218
1.3000	.1404	.3803	.7640	.0831	.0173
1.3500	.1161	.3323	.7508	.0637	.0135
1.4000	.0906	.2821	.7157	.0462	.0103
1.4500	.0645	.2319	.6414	.0307	.0076
1.5000	.0384	.1849	.4962	.0171	.0055
1.5500	.0137	.1453	.2323	.0057	.0039

PROPELLER NUMBER =4214 PITCH RATIO = 1.43 SIGMA = 1.697

J	KTOUT	10KQOUT	EFFIC	KT/J2	KQ/J3
1.0000	.2778	.6171	.7165	.2778	.0617
1.0500	.2490	.5779	.7173	.2250	.0499
1.1000	.2235	.5418	.7222	.1847	.0407
1.1500	.2020	.5061	.7304	.1527	.0333
1.2000	.1815	.4686	.7398	.1261	.0271
1.2500	.1608	.4279	.7475	.1029	.0219
1.3000	.1389	.3834	.7493	.0822	.0175
1.3500	.1153	.3352	.7388	.0632	.0136
1.4000	.0900	.2842	.7058	.0459	.0104
1.4500	.0636	.2320	.6327	.0302	.0076
1.5000	.0369	.1809	.4870	.0164	.0054
1.5500	.0113	.1341	.2067	.0047	.0036

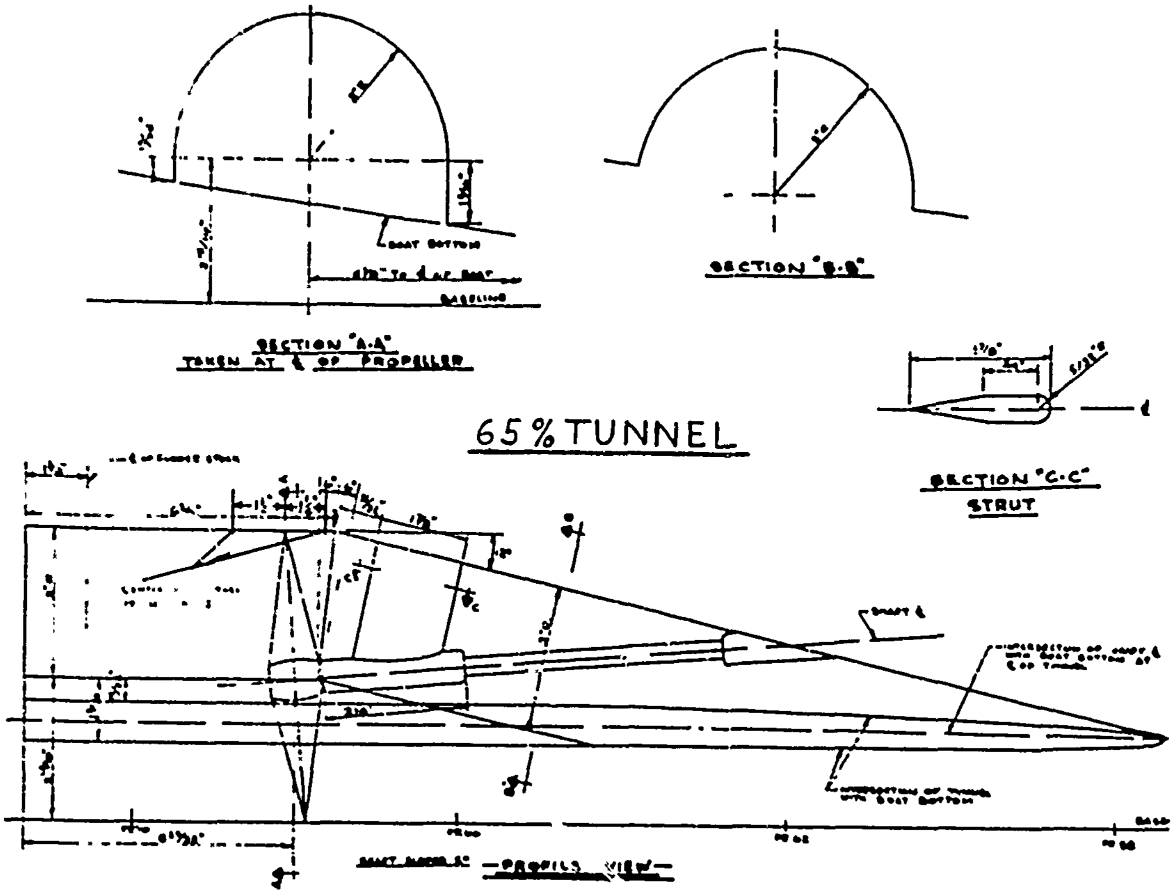
PROPELLER NUMBER =4214 PITCH RATIO = 1.43 SIGMA = 1.131

J	KTOUT	10KQOUT	EFFIC	KT/J2	KQ/J3
1.0000	.2391	.5584	.6814	.2391	.0558
1.0500	.2351	.5582	.7037	.2132	.0482
1.1000	.2235	.5431	.7204	.1847	.0408
1.1500	.2063	.5158	.7321	.1560	.0339
1.2000	.1852	.4784	.7394	.1286	.0277
1.2500	.1616	.4333	.7419	.1034	.0222
1.3000	.1365	.3825	.7383	.0808	.0174
1.3500	.1108	.3281	.7256	.0608	.0133
1.4000	.0851	.2720	.6969	.0434	.0099
1.4500	.0595	.2159	.6364	.0283	.0071
1.5000	.0367	.1614	.5053	.0152	.0048
1.5500	.0097	.1102	.1946	.0036	.0030

PROPELLER NUMBER =4214 PITCH RATIO = 1.43 SIGMA = .565

J	KTOUT	10KQOUT	EFFIC	KT/J2	KQ/J3
1.0000	.1463	.3485	.6680	.1463	.0349
1.0500	.1576	.3805	.6923	.1439	.0329
1.1000	.1636	.4027	.7115	.1352	.0303
1.1500	.1637	.4124	.7264	.1238	.0271
1.2000	.1575	.4084	.7366	.1094	.0236
1.2500	.1453	.3901	.7410	.0930	.0200
1.3000	.1277	.3582	.7373	.0755	.0163
1.3500	.1055	.3144	.7213	.0579	.0128
1.4000	.0803	.2611	.6849	.0410	.0095
1.4500	.0536	.2022	.6121	.0255	.0066
1.5000	.0277	.1422	.4658	.0123	.0042
1.5500	.0052	.0868	.1466	.0021	.0023

TABLE 6 - Cavitation Performance Characteristics of Propeller 4214 in the Tunnel Hull



Prop ller 4175 Propeller 4214

Figure 1 - Drawing of Model Tunnel Hull and Photographs of Model Propellers

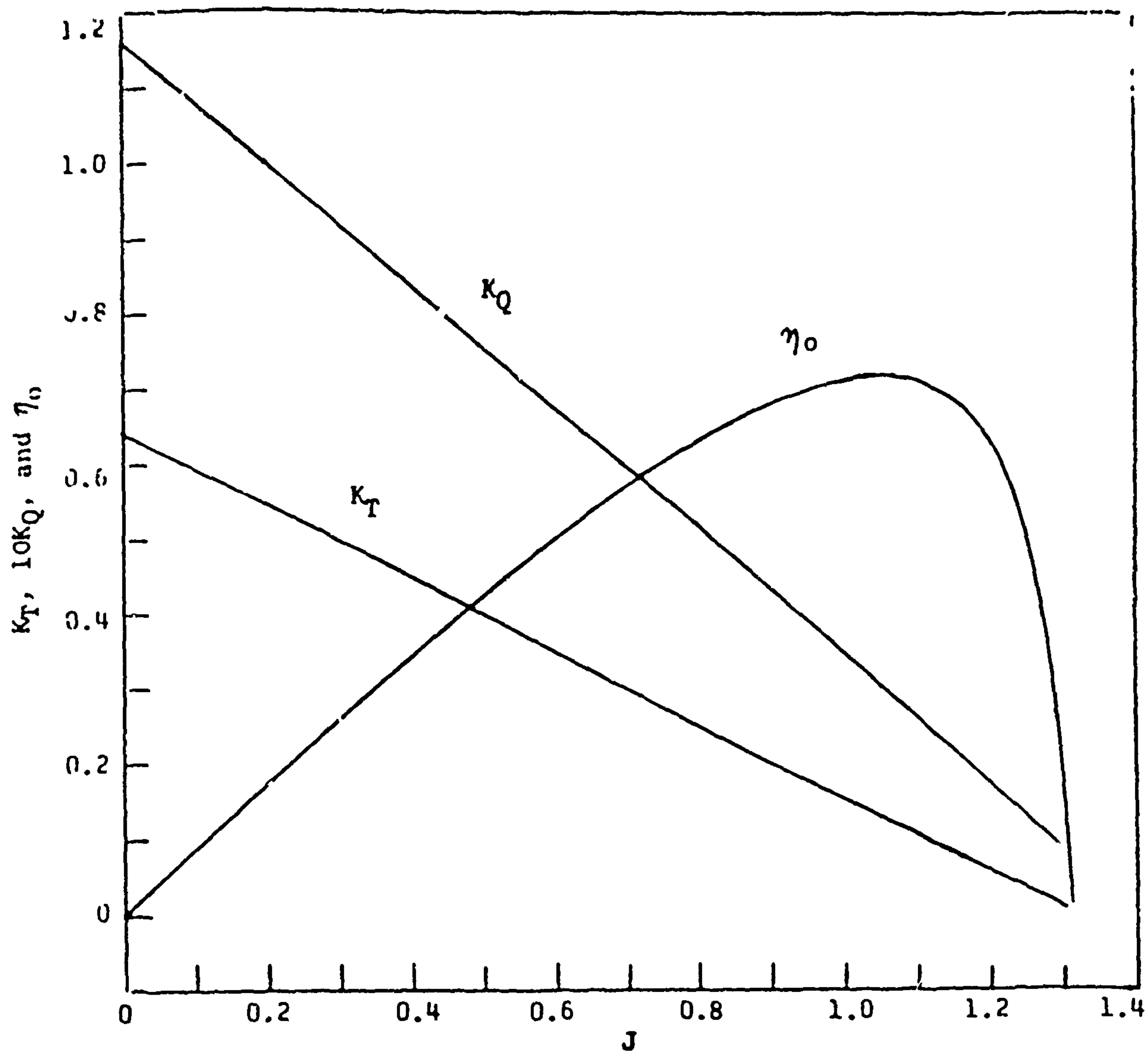


Figure 2 - Open Water Characteristics of Propeller 4175

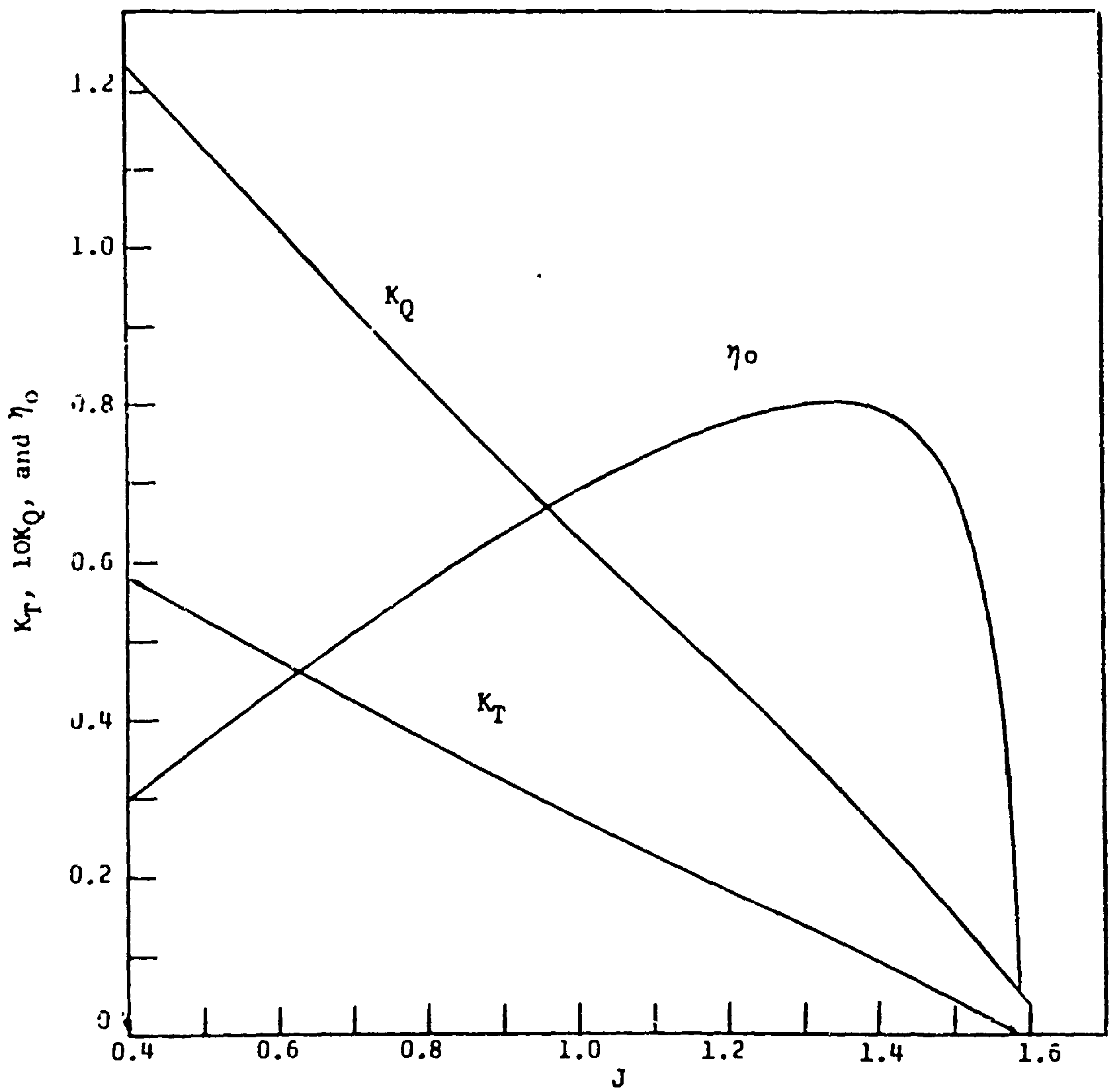


Figure 3 - Open Water Characteristics of Propeller 4214

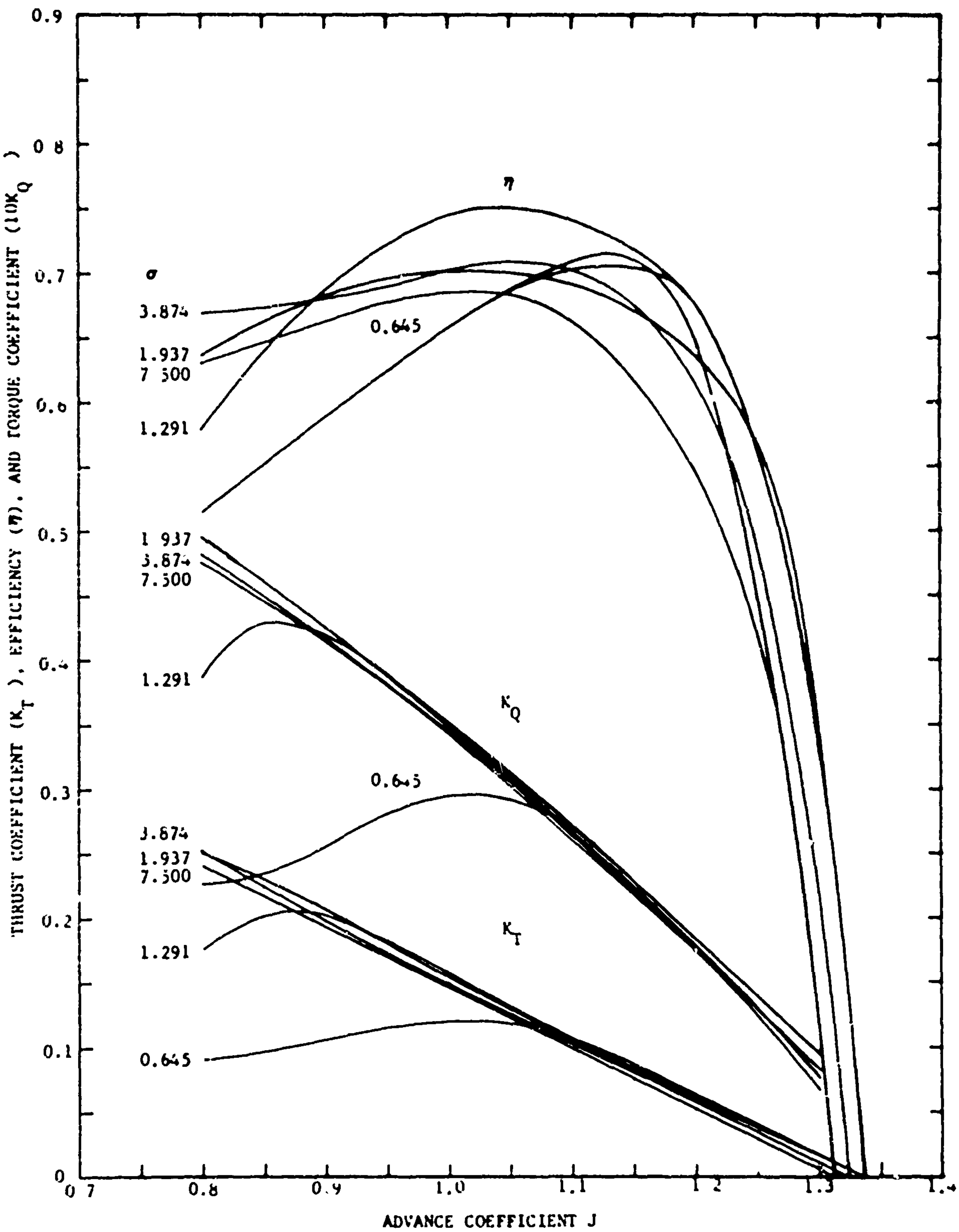


Figure 4 - Cavitation Performance of Propeller 4175 in Uniform Flow

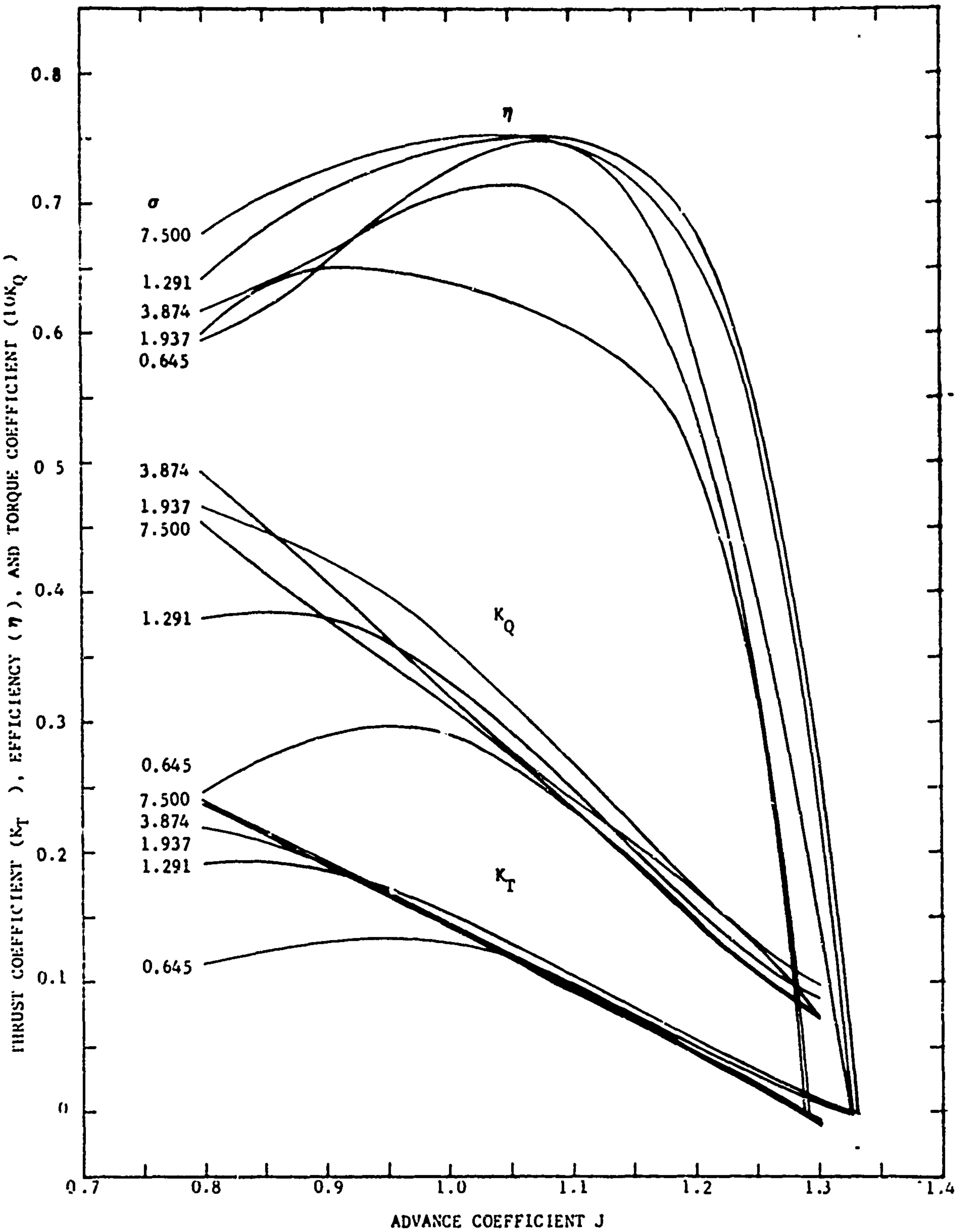


Figure 5 - Cavitation Performance of Propeller 4175 in the Tunnel Hull

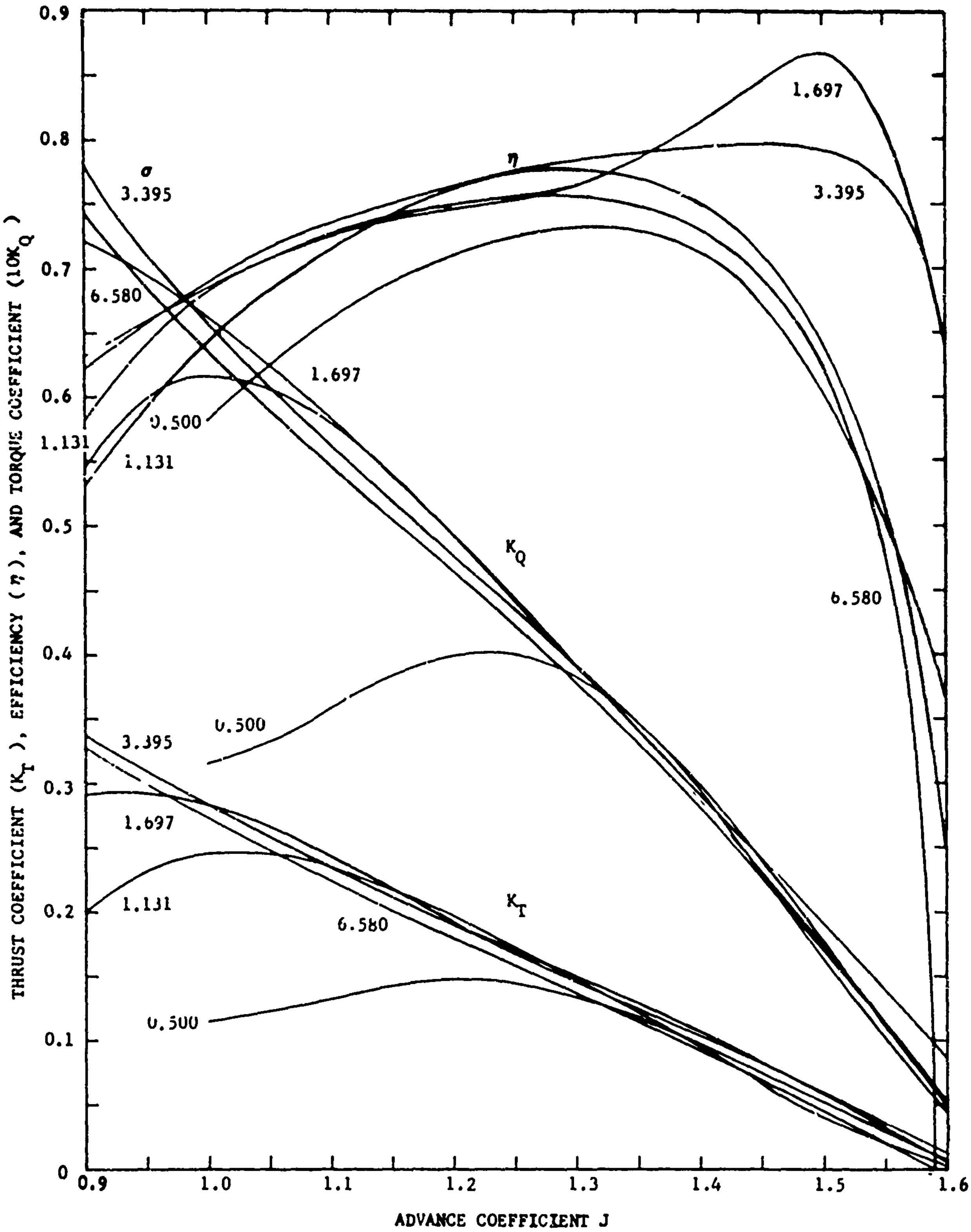


Figure 6 - Cavitation Performance of Propeller 4214 in Uniform Flow

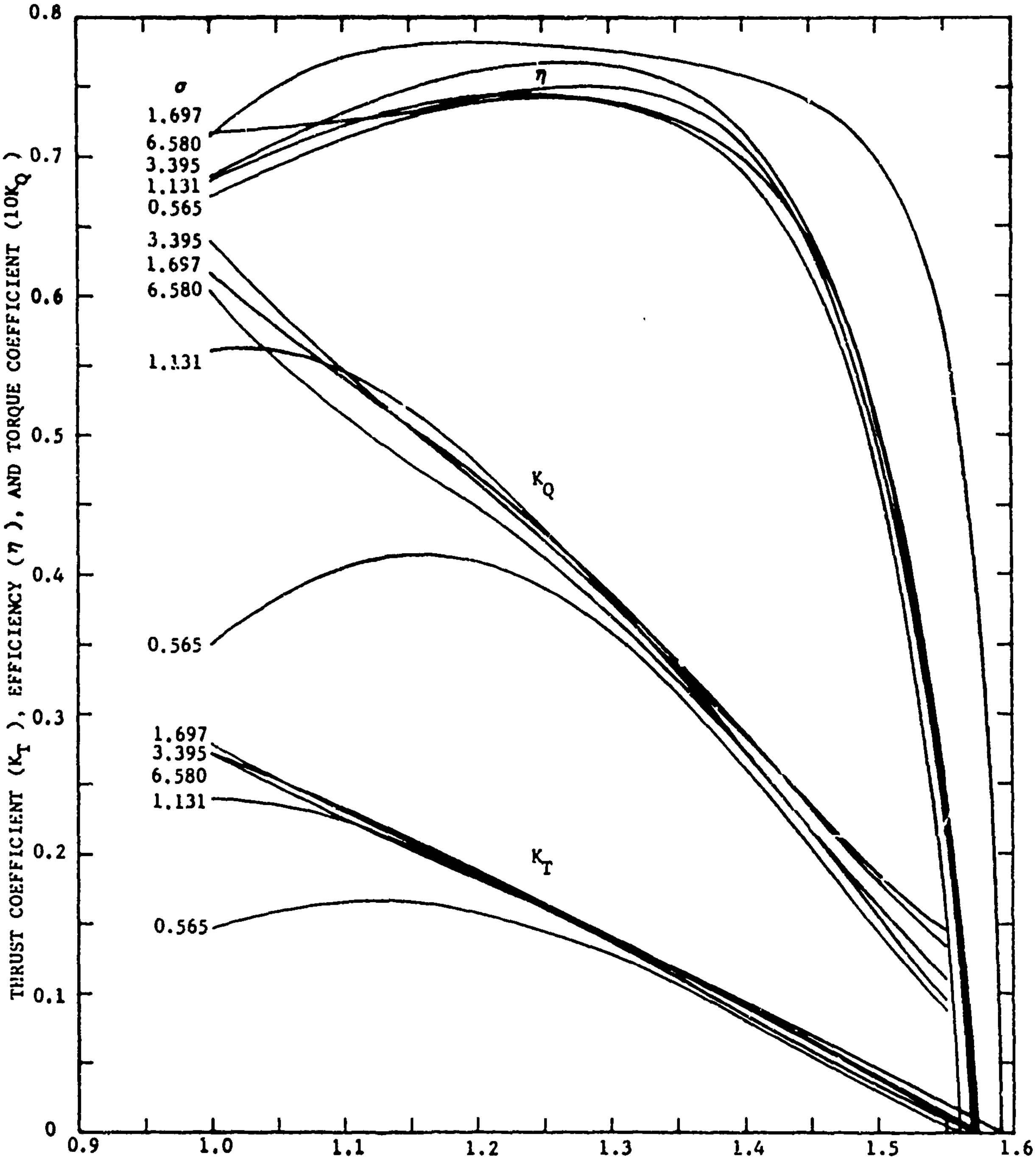


Figure 7 - Cavitation Performance of Propeller 4214 in the Tunnel Hull

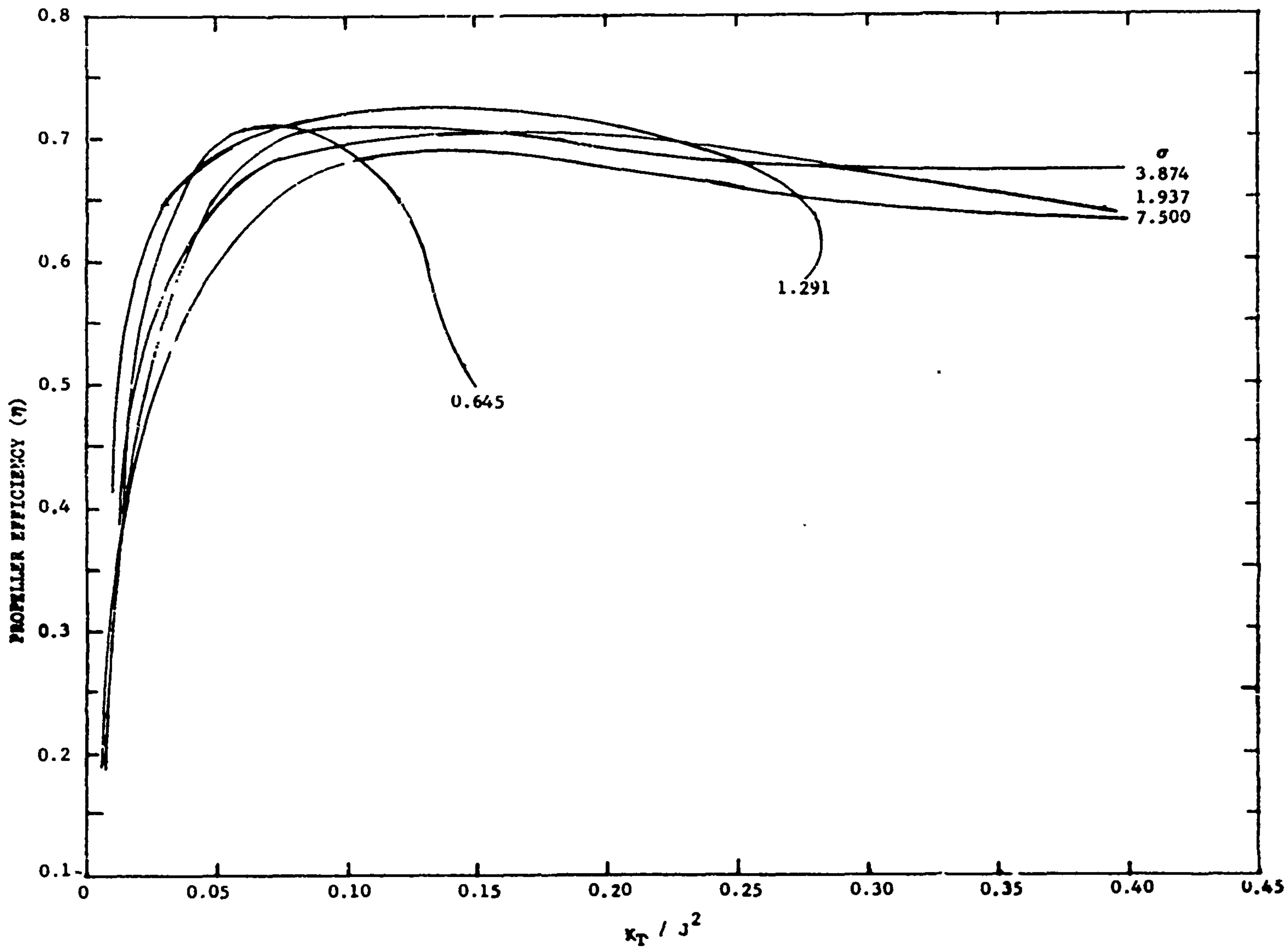


Figure 8 - Propeller 4175 Efficiencies versus K_T/J^2 for Various Cavitation Numbers in Uniform Flow

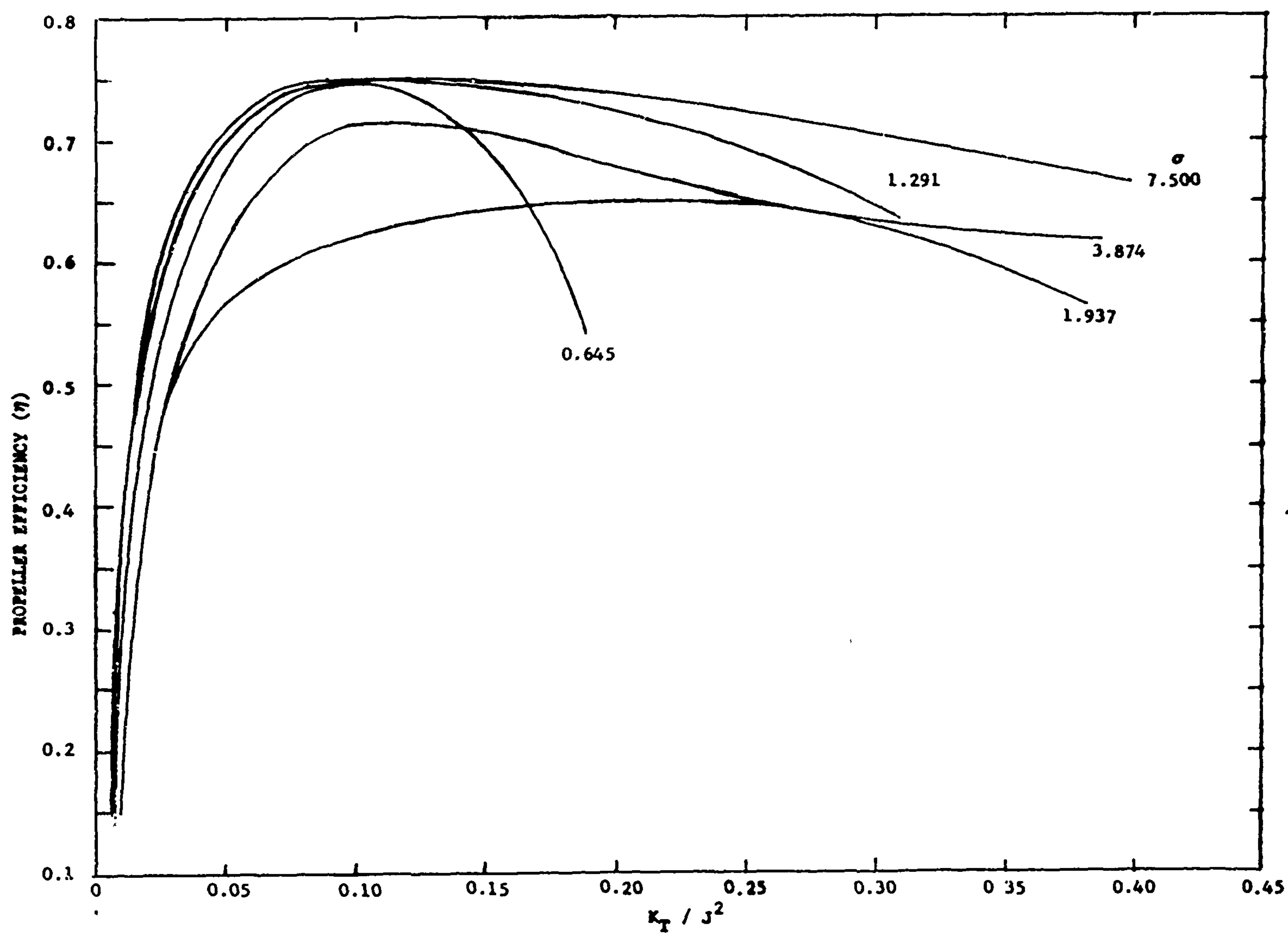


Figure 9 - Propeller 4175 Efficiencies versus K_T/J^2 for Various Cavitation Numbers in the Tunnel Hull

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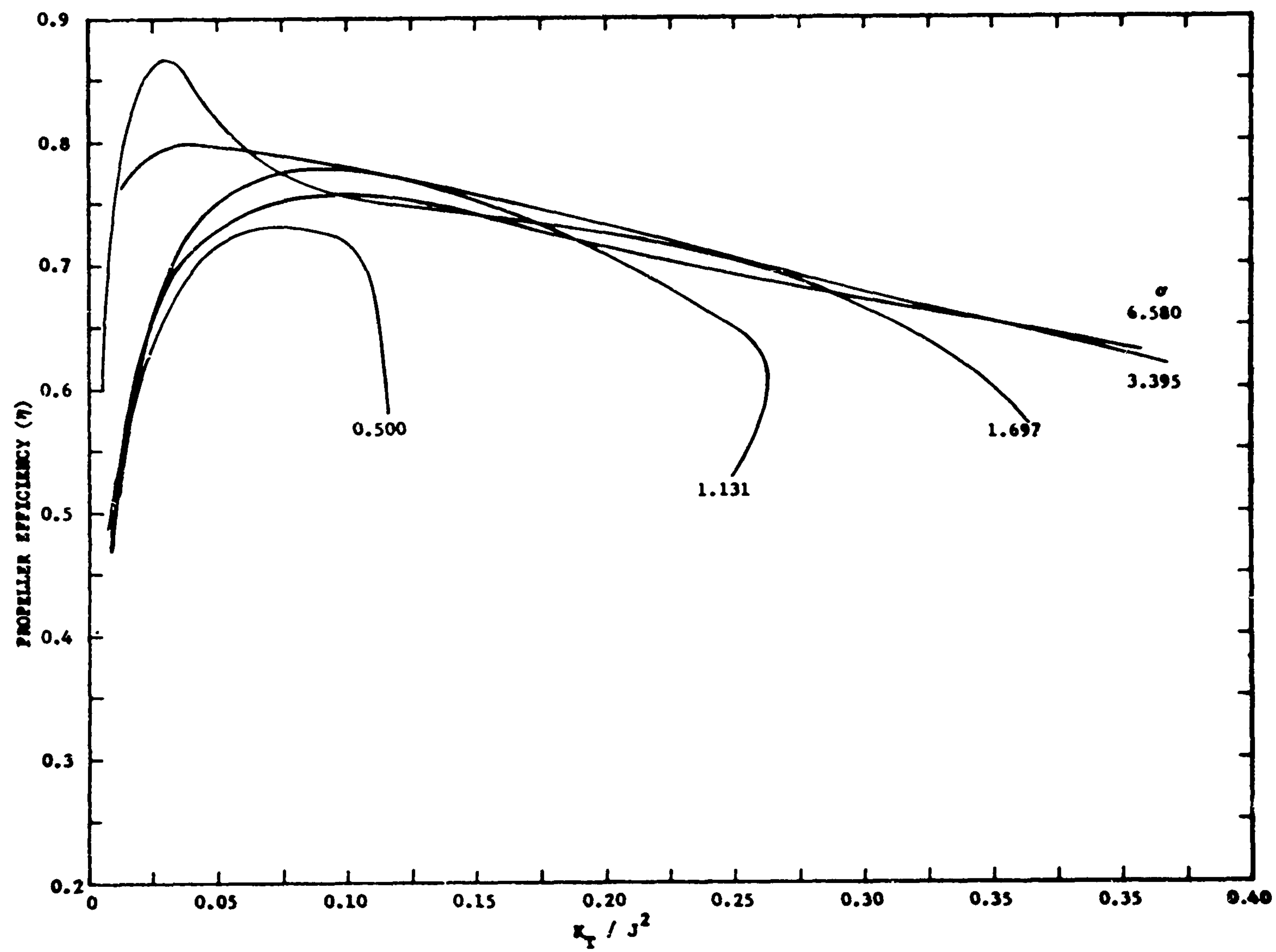

Figure 10 - Propeller 4214 Efficiencies versus K_T/J^2 for Various Cavitation Numbers in Uniform Flow

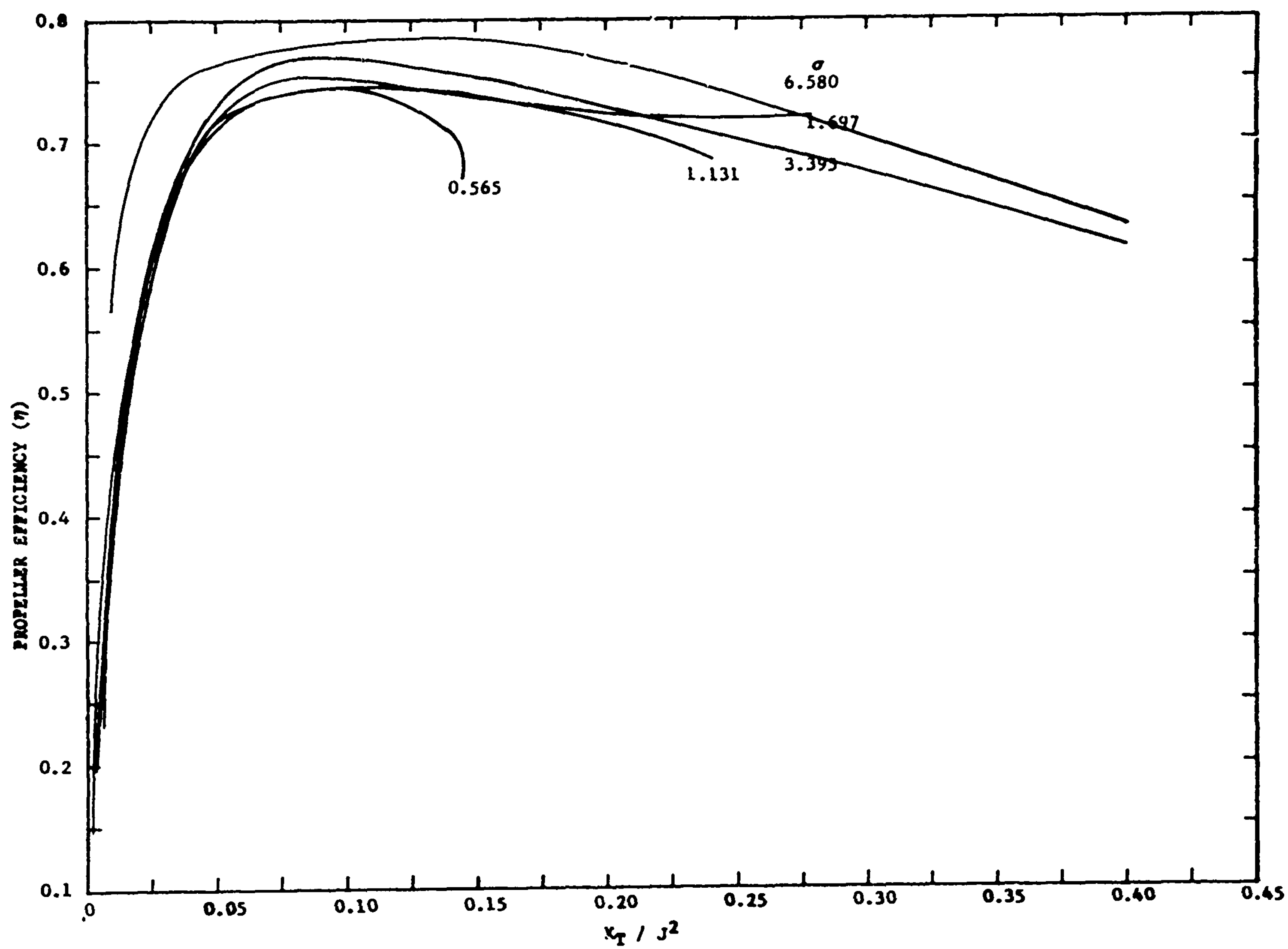

Figure 11 - Propeller 4214 Efficiencies versus K_T/J^2 for Various Cavitation Numbers in the Tunnel Hull

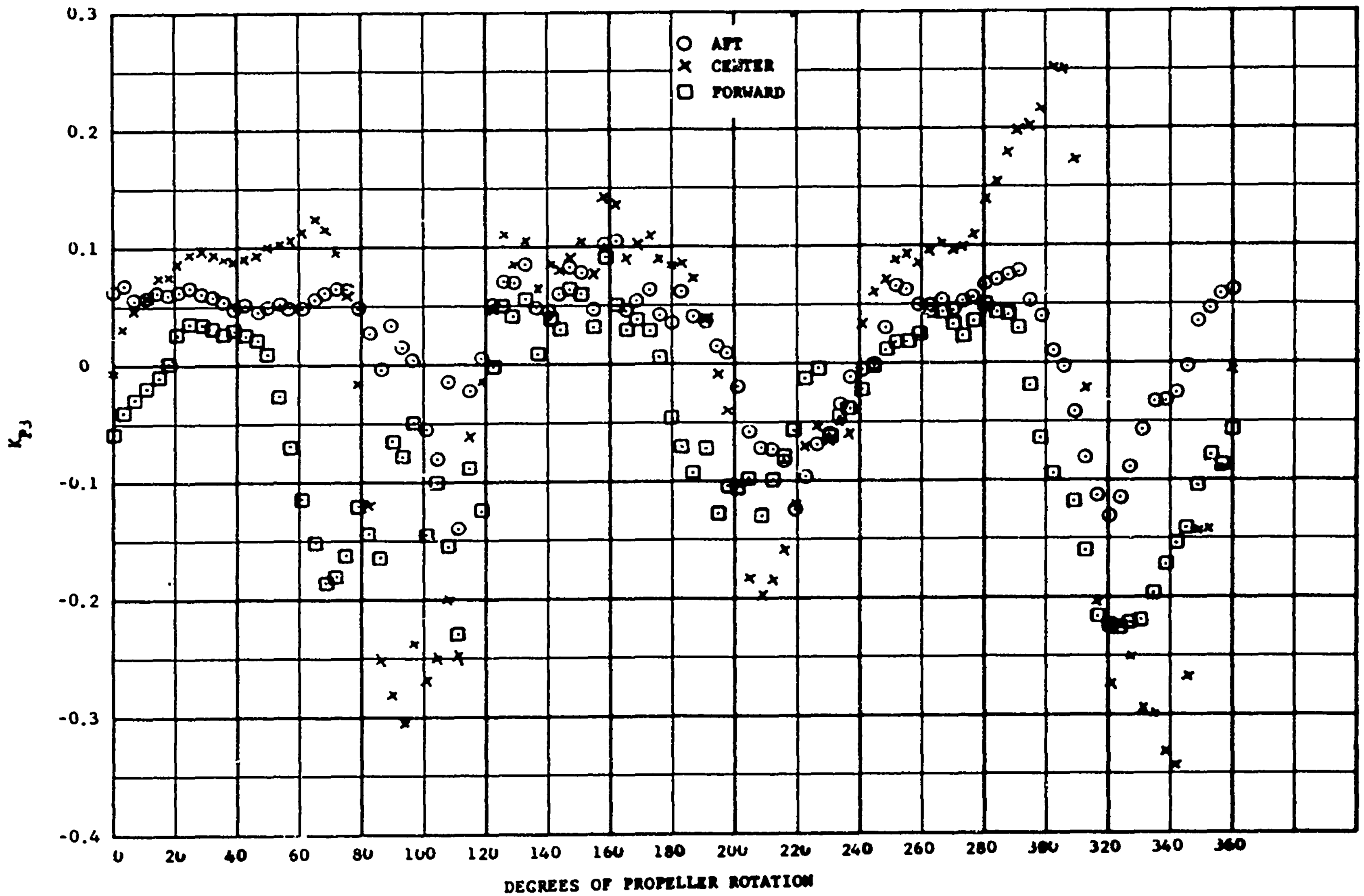

Figure 12 - Typical Induced Pressure Variation with Propeller Rotation for Propeller 4175

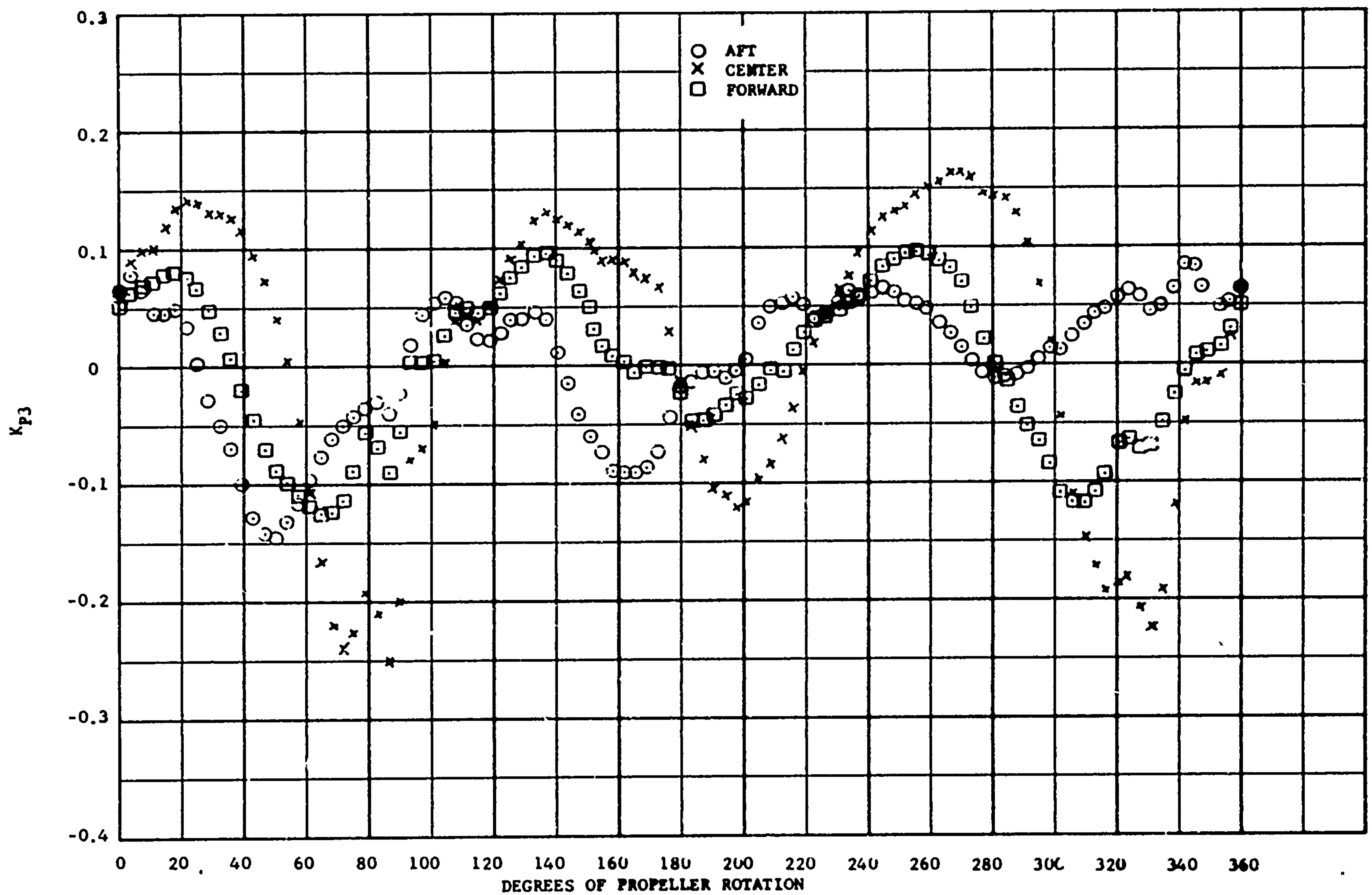

Figure 13 - Typical Induced Pressure Variation with Propeller Rotation for Propeller 4214

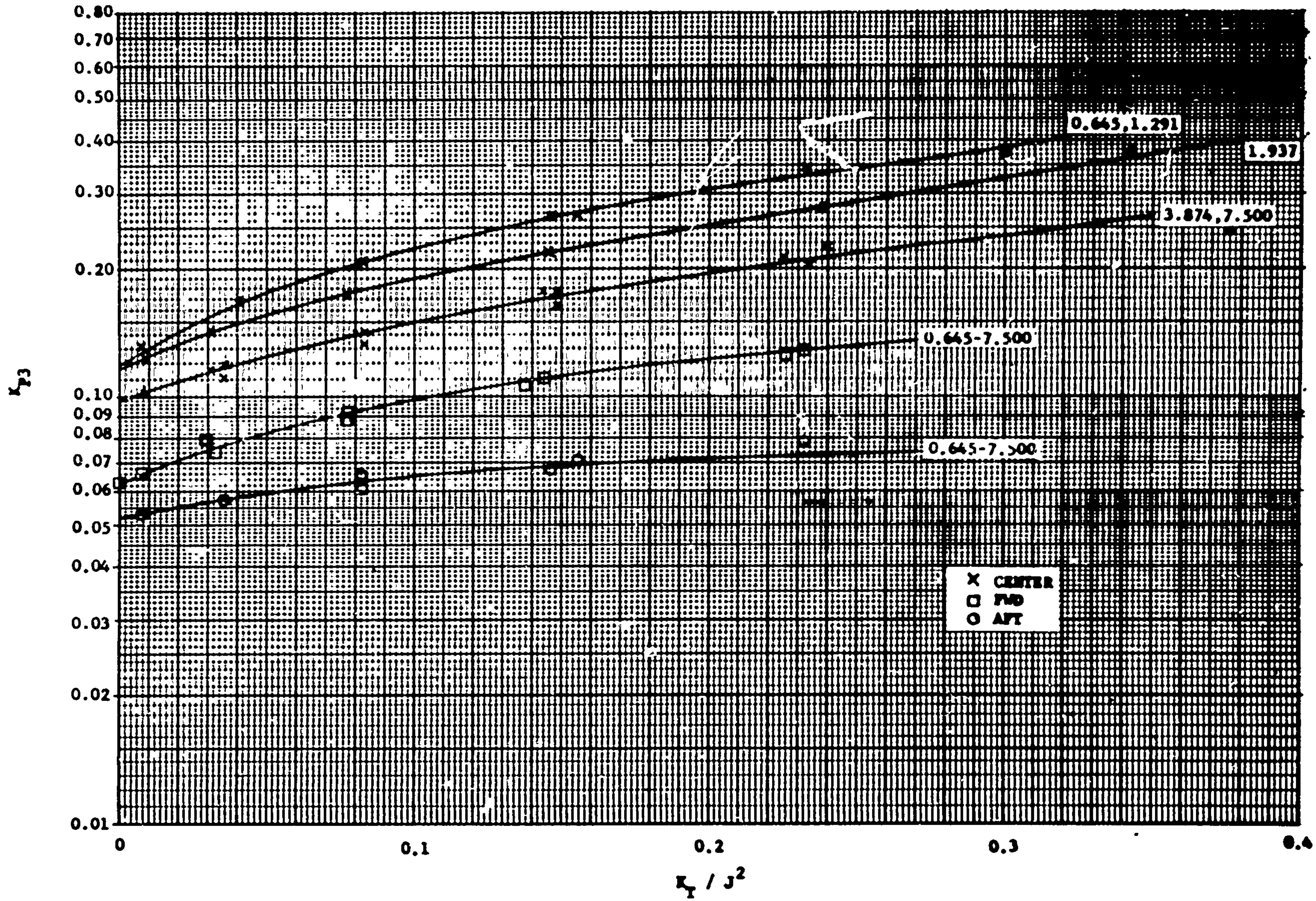

Figure 14 - Measured Blade-Frequency Amplitudes versus Propeller Loading for Propeller 4175

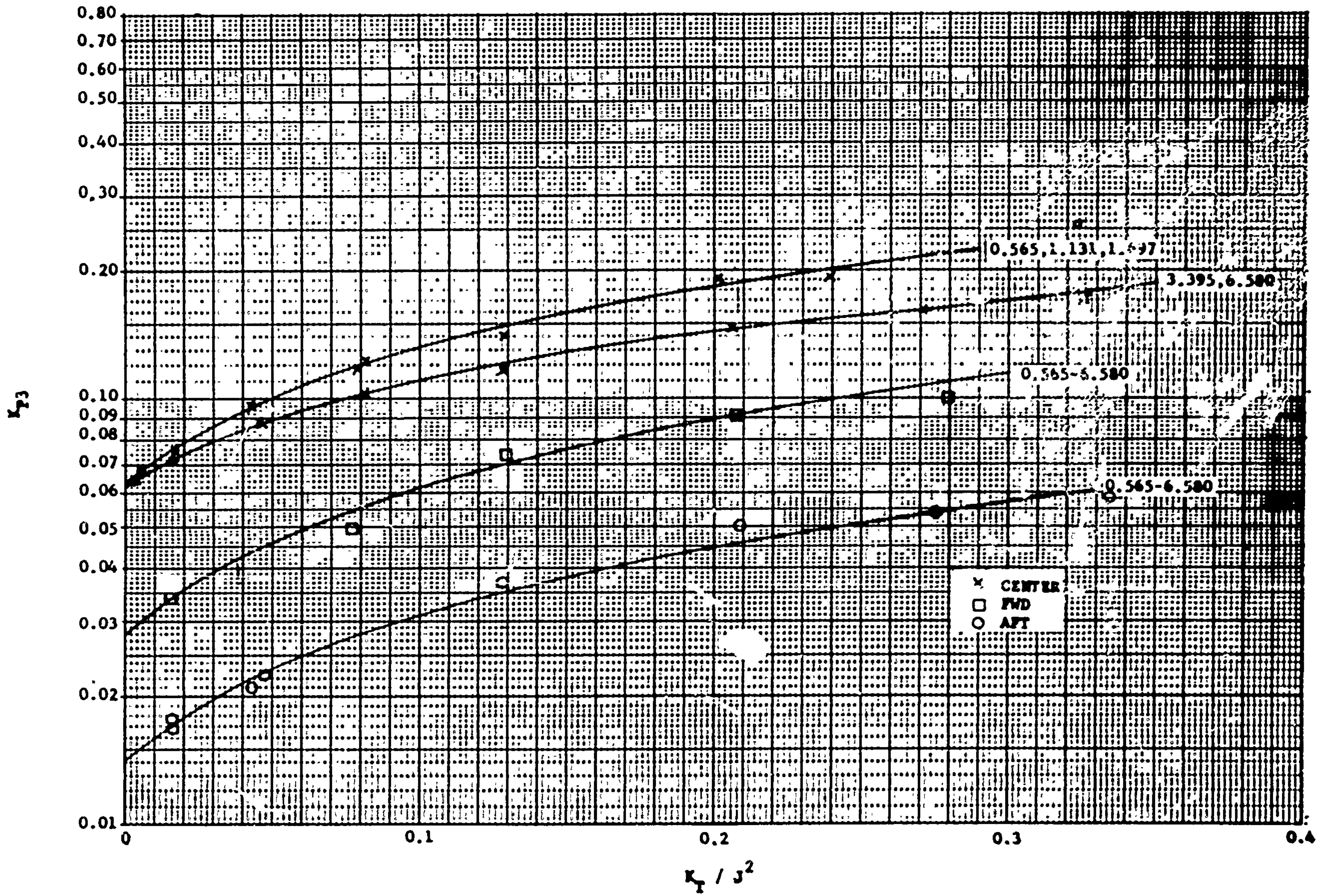

Figure 15 - Measured Blade-Frequency Amplitudes versus Propeller Loading for Propeller 4214

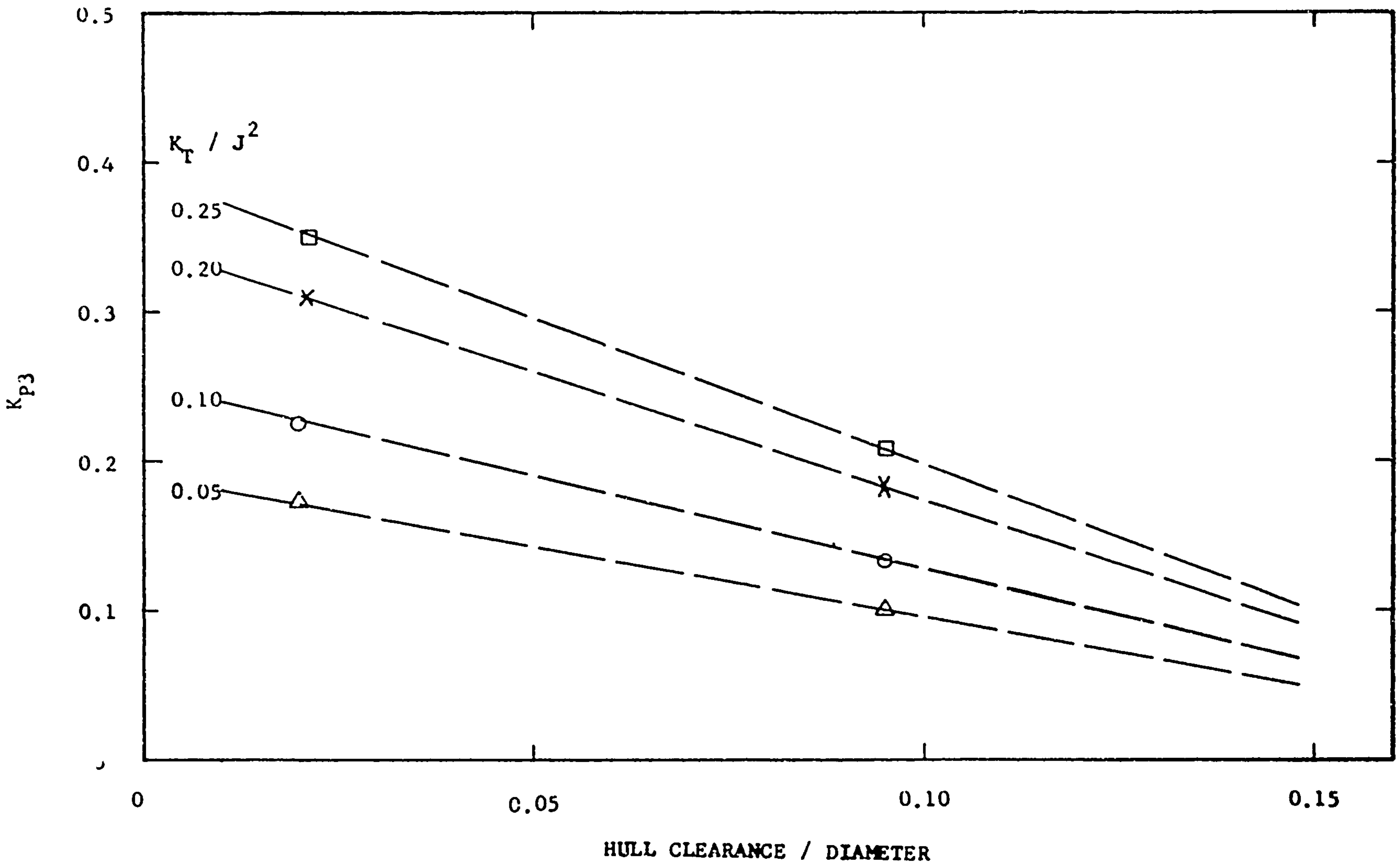

Figure 16 - Measured Blade-Frequency Amplitudes versus Hull Clearance for Various Propeller Loadings -

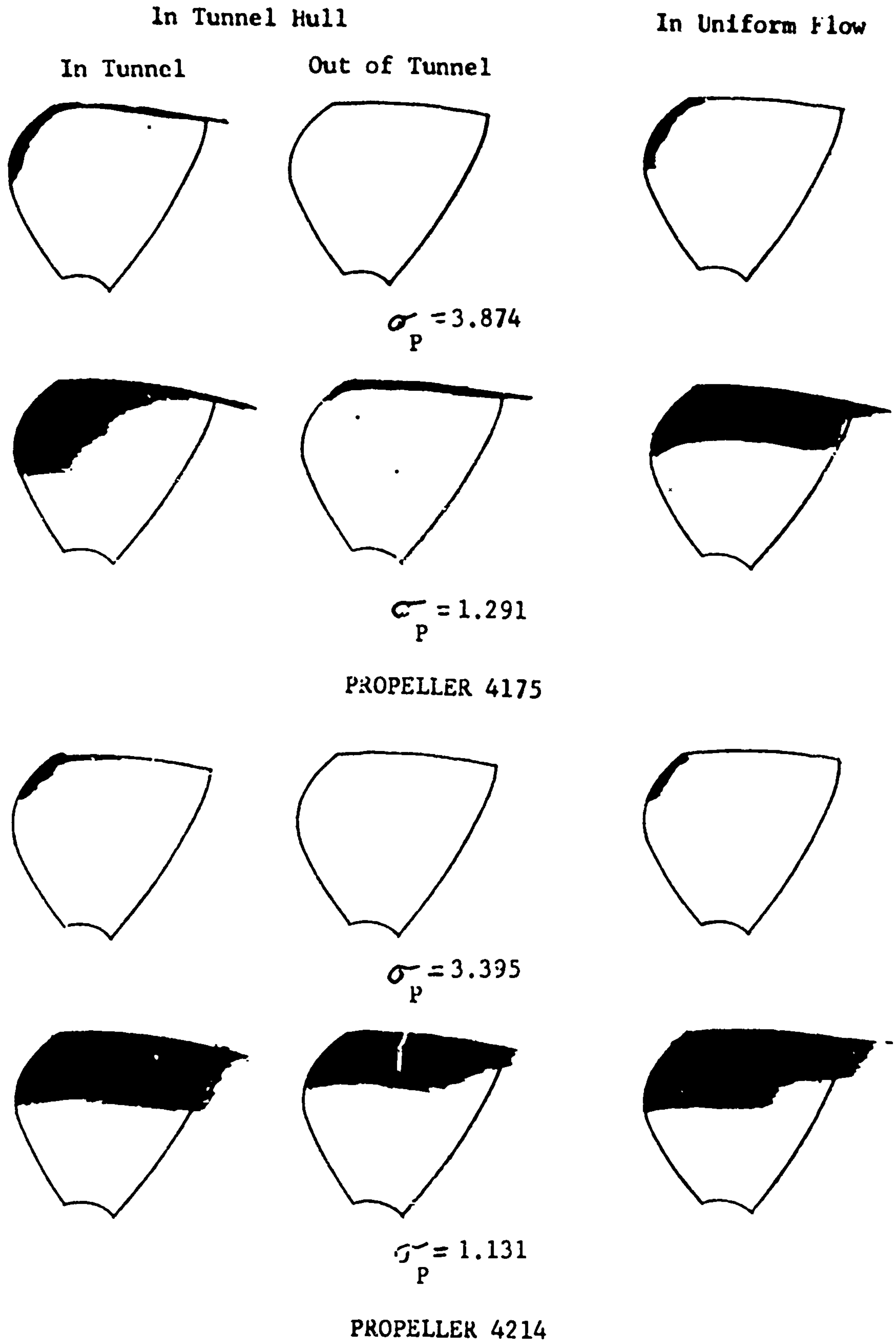

Figure 17 - Sketches of Cavitation Present on Propellers 4175 and 4214 in the Tunnel Hull and in Uniform Flow, $K_T/J^2 = 0.232$ and Two Sigmas

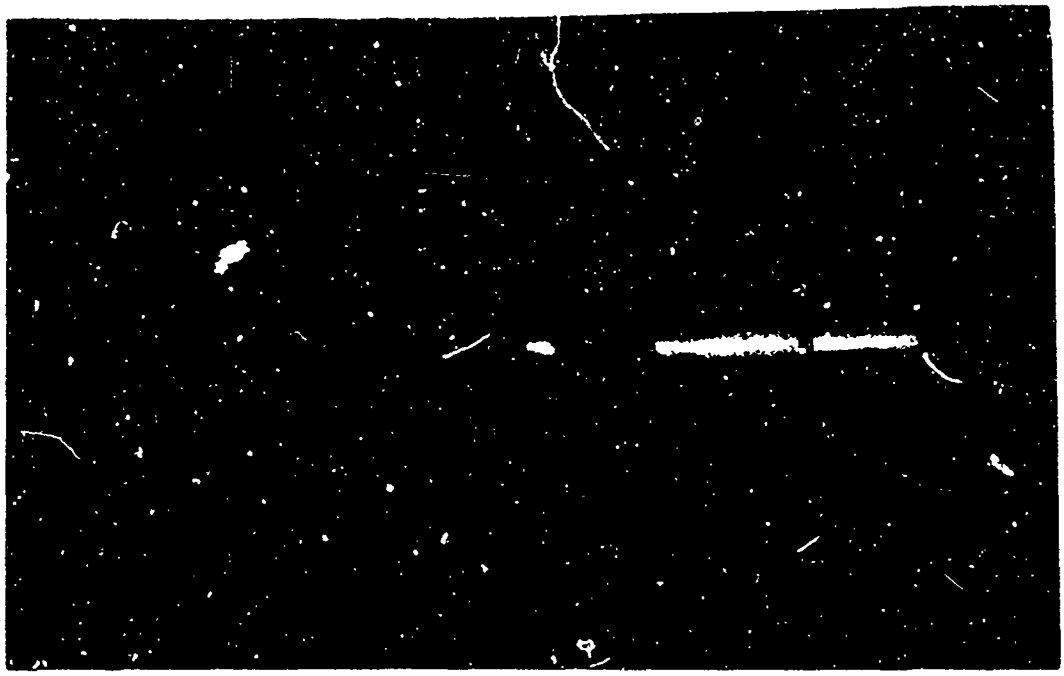

Figure 18 - Photographs of Propeller 4175 in Uniform Flow and in the Tunnel Hull at σ_p = 1.291 and K_T/J^2 = 0.232